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Regueiro

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[54] **LEAD SCREW DRIVEN SHAFT PHASE CONTROL MECHANISM**

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[73] Assignee: **Chrysler Corporation**, Auburn Hills, Mich.

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 493,605, Jun. 22, 1995, abandoned.

[51] **Int. Cl.**^{6} **F01L 1/344**

[52] **U.S. Cl.** .... **123/90.17**; 123/90.31; 123/501; 123/503; 464/2; 74/568 R

[58] **Field of Search** .... 123/90.15, 90.17, 123/90.31, 500, 501, 503, 504; 74/567, 568 R; 464/1, 2, 160

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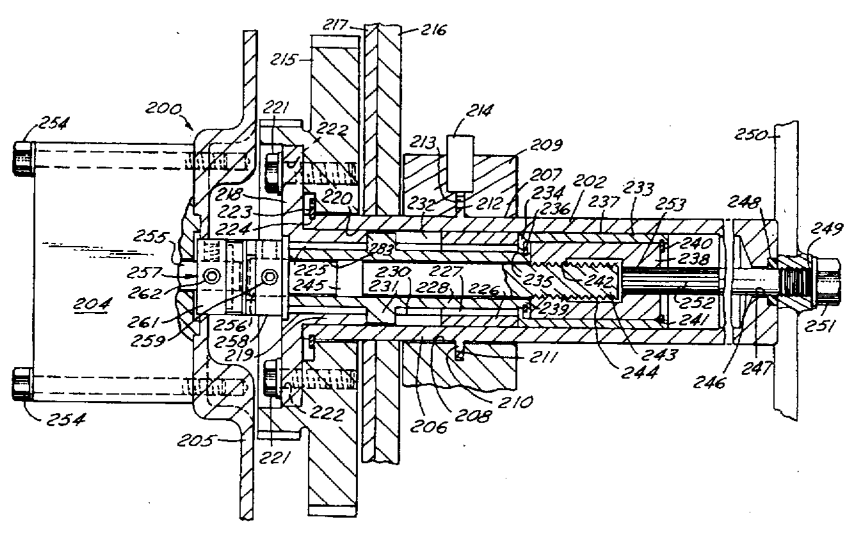
[57] **ABSTRACT**

A camshaft timing device includes a camshaft **10** and a drive gear **20** rotatably mounted thereon. An interconnecting shifting shaft **30** has spline **31** and **33** that interconnect with respective splines **16** and **41** on the camshaft and a hub of a drive gear **20**. Axial movement of the shaft **30** causes the shaft to rotate the camshaft **30** with respect to the drive gear **20** due to the helical nature of the splines **33** and **41**. The axial movement of the shaft **30** is caused by a drive sleeve **50** connected to a pinion gear that is driven through a worm gear **63** by an electric motor **67**.

8 Claims, 6 Drawing Sheets



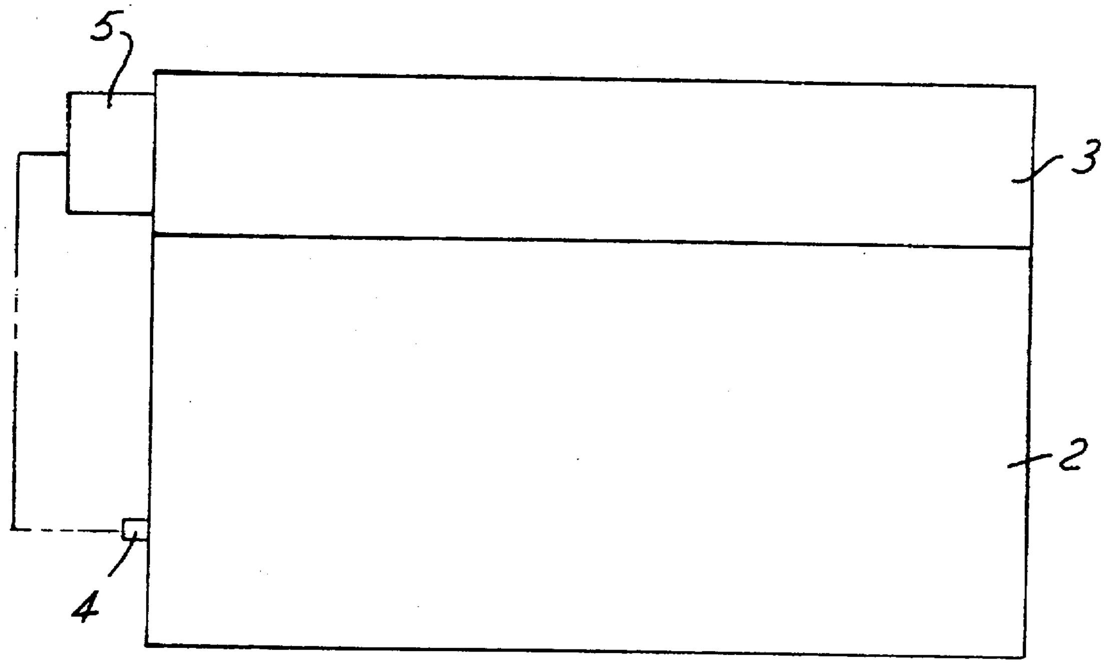


FIG. 1

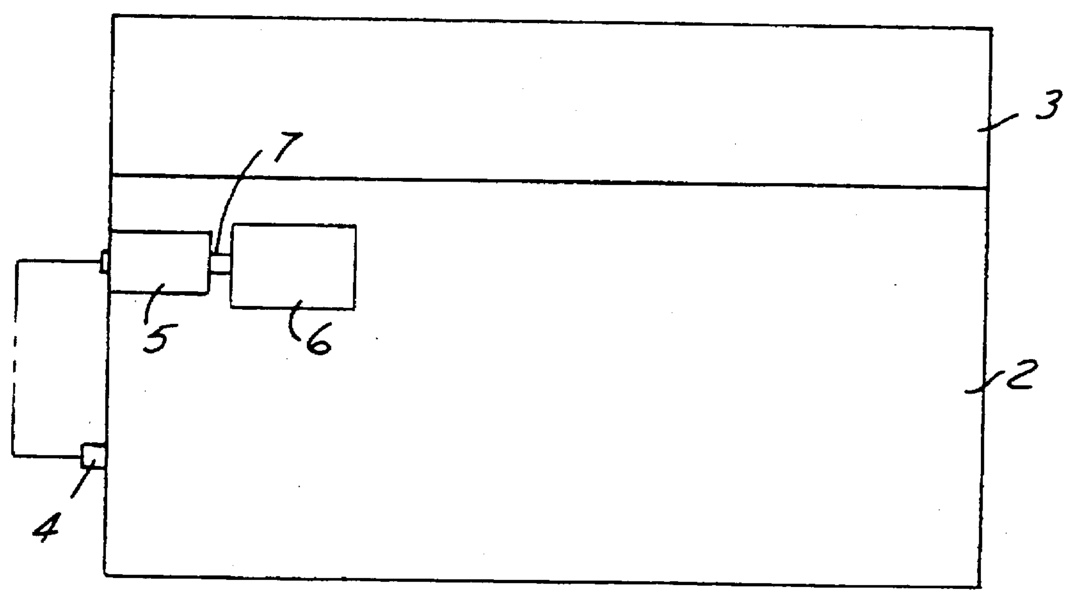


FIG. 2

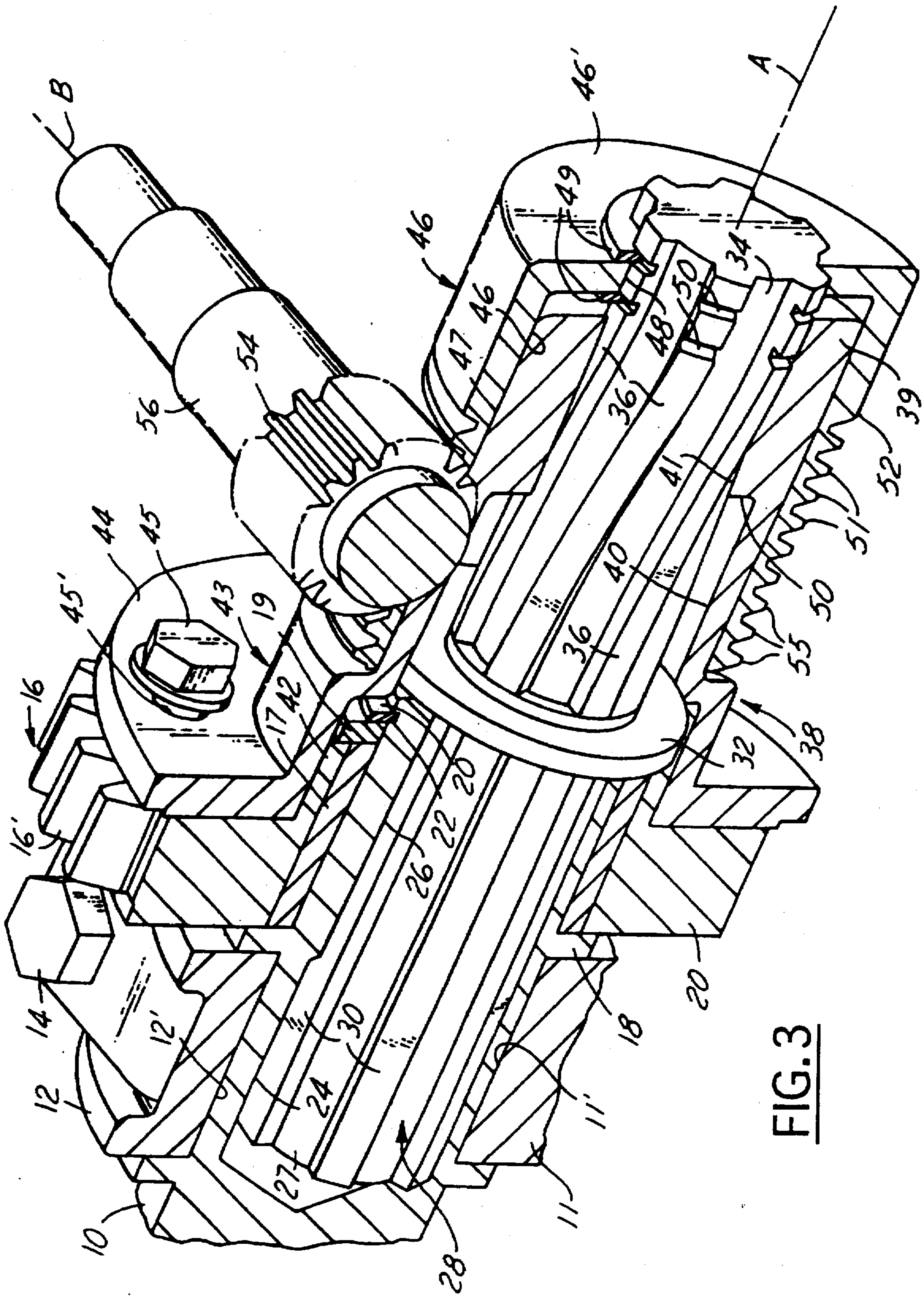


FIG. 3

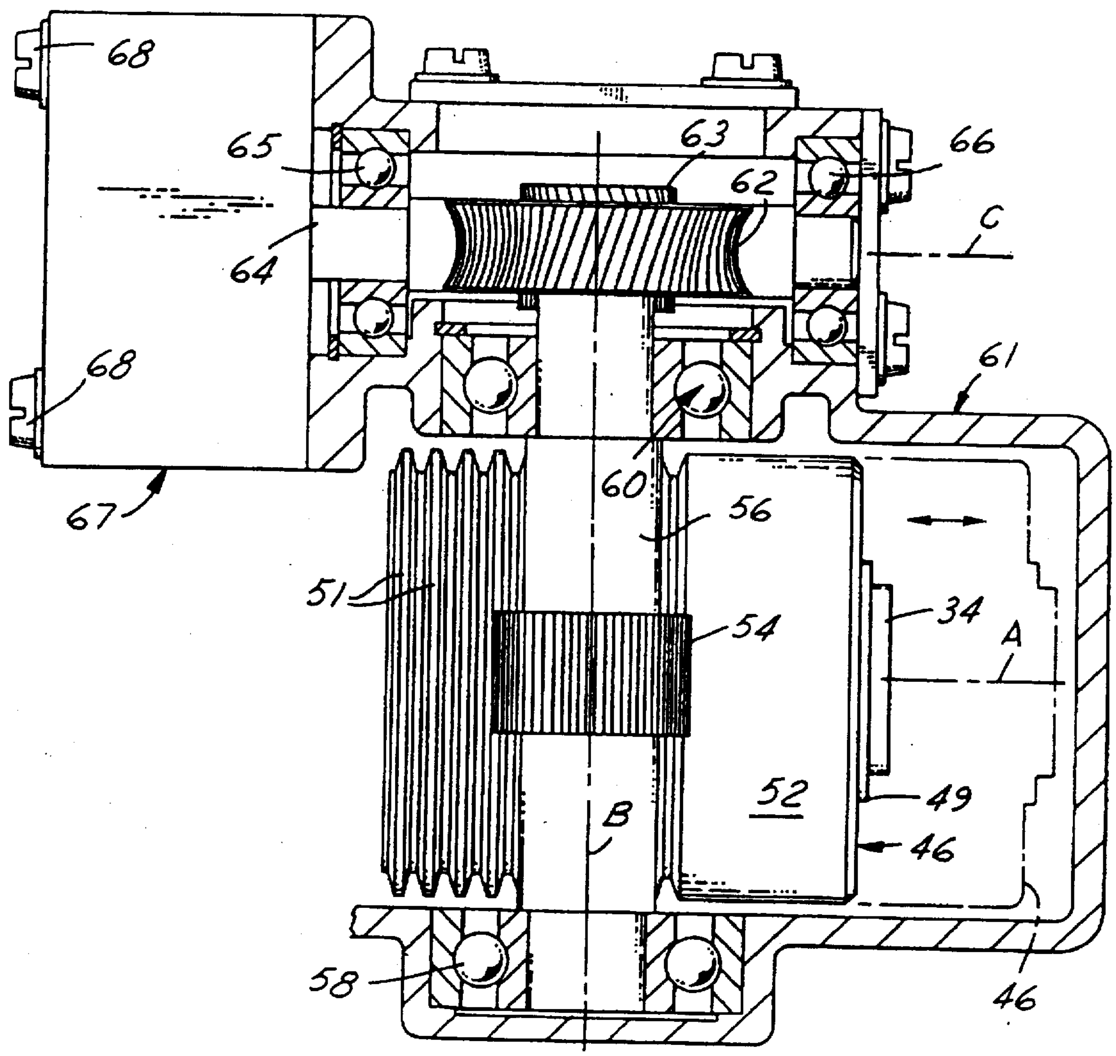
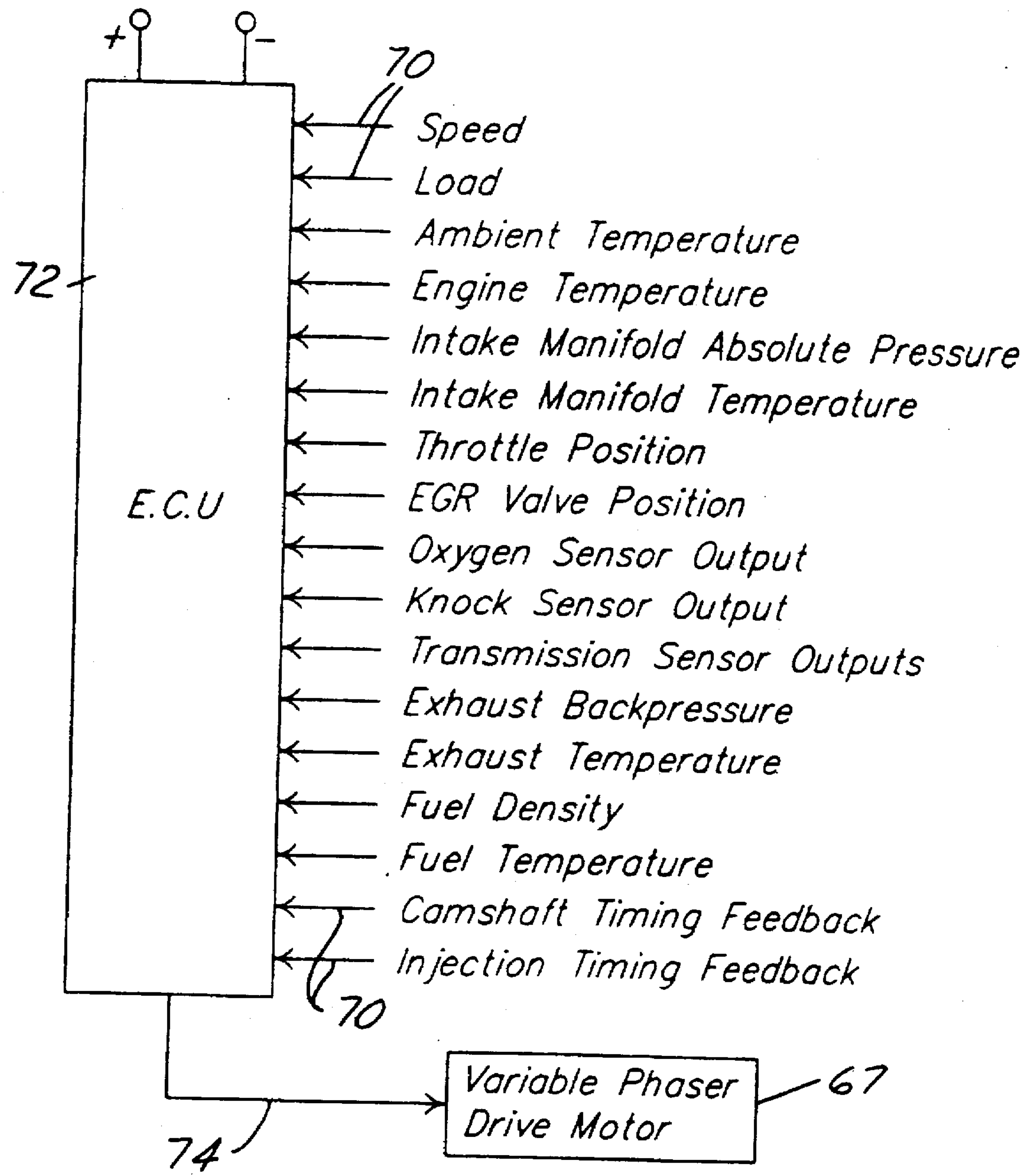


FIG. 4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Intake Manifold Absolute Pressure
Intake Manifold Temperature
Throttle Position
EGR Valve Position
Oxygen Sensor Output
Knock Sensor Output
Transmission Sensor Outputs
Exhaust Backpressure
Exhaust Temperature
Fuel Density
Fuel Temperature
Camshaft Timing Feedback
Injection Timing Feedback
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Variable Phaser Drive Motor
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FIG. 5

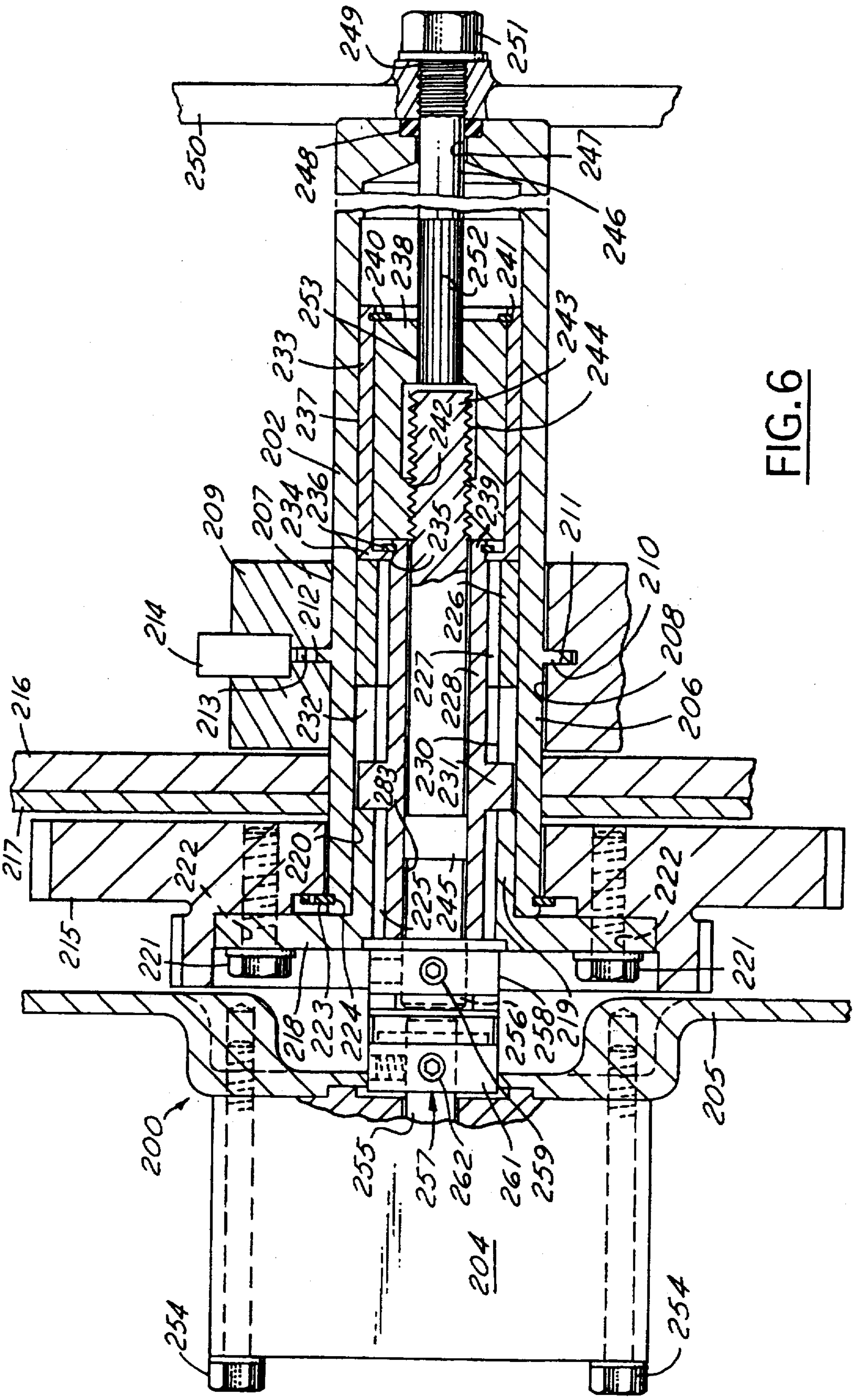
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FIG. 6

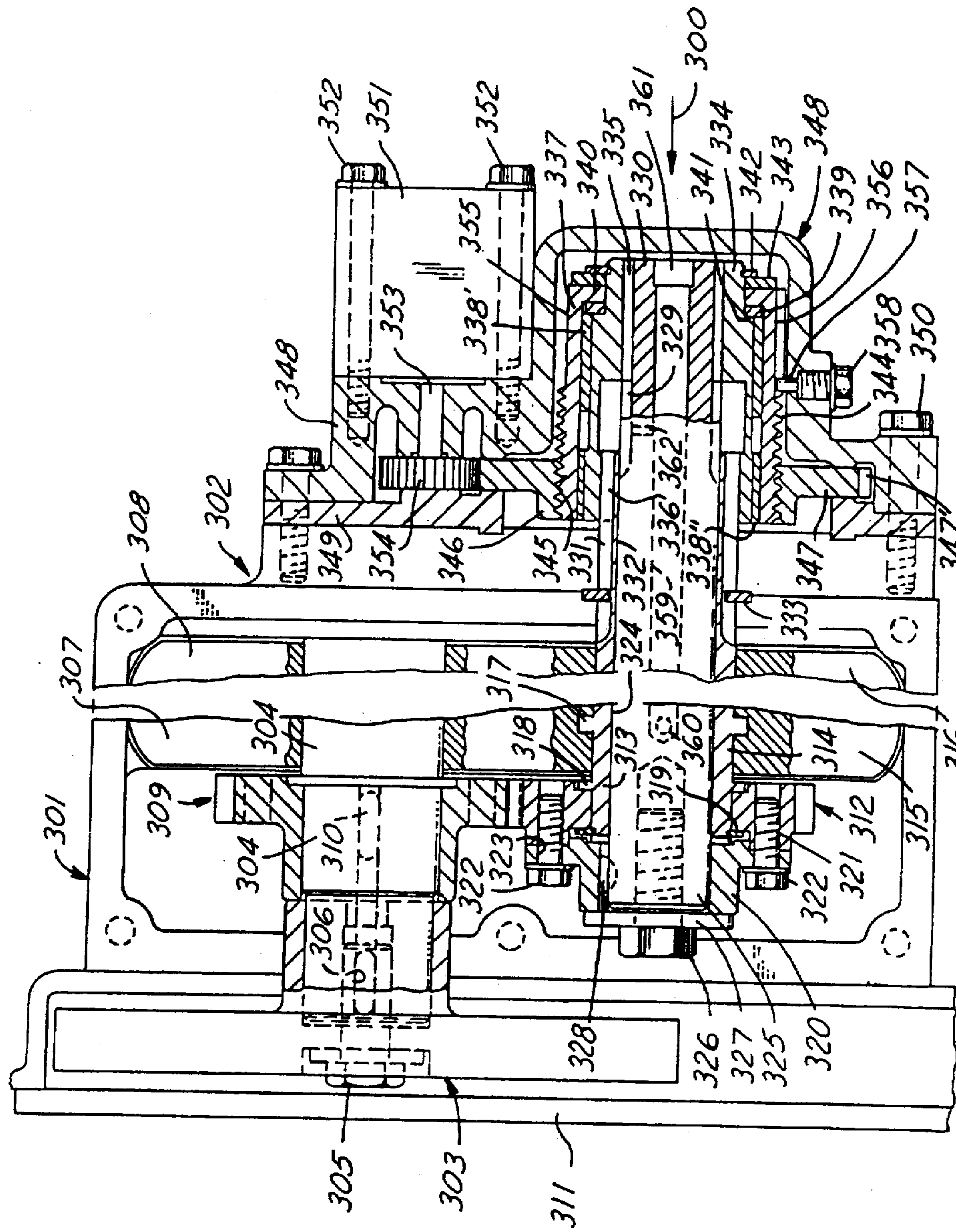
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FIG.7

LEAD SCREW DRIVEN SHAFT PHASE CONTROL MECHANISM

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of application Ser. No. 08/493,605, filed Jun. 22, 1995, now abandoned, entitled "An Angular Phase Controlling System for Controlling the Timing of Rotatable Shafts" by the same inventor (sole) as in the subject application.

TECHNICAL FIELD

The field of this invention relates to mechanisms for coupling two coaxial rotatable shafts in a manner permitting selective adjustment of their respective angular phase relationship, particularly useful with internal combustion engines for providing a variable valve timing system or for providing a selectively timed fuel injection pump system.

BACKGROUND OF THE DISCLOSURE

For use in powering a vehicle, an internal combustion engine must react to a variety of operating conditions to effectively provide desired performance. A technic to achieve such desired performance is to provide a system to selectively adjust the timing or phasing of the opening and closing of the engine's valves relative to rotation of the engine's crankshaft. Selective control of the intake valves is particularly effective. Likewise, particularly as concerns diesel engines, selective control of the timing of a fuel injection pump would appear to offer distinct advantages.

Known devices include sections of two rotating shafts being machined with splines with at least one of the shafts having helical splines. Another connecting shaft or shifting sleeve engages one rotating shaft with the other rotating shaft and has two sets of splines designed to mesh with the respective rotating shafts. The relative rotation between the rotating shafts and the connecting shaft may take place simultaneously with otherwise high speed rotation of the entire assembly under engine load conditions.

In known systems of the type previously discussed above, the shifting sleeve is typically activated by a large piston which may be coaxially mounted relative to the shifting sleeve. This piston is moved in a first axial direction by a force created by application of pressurized engine oil as directed to one end of the piston by control of a solenoid operated valve. When the force produced by the pressurized oil is absent, a return spring typically biases the piston in a second opposite axial direction. Thus, the aforedescribed known mechanism basically produces a two-position timing or phasing function. This means that the system is not capable of selectively producing a stable, intermediate position between the first and second end positions of the piston. The inability to achieve such a stable intermediate position compromises optimal valve timing of an engine. If the aforedescribed system attempts to achieve an intermediate position, the return spring provided to bias and return the piston to the first position is subjected to cam torque impulse forces which undesirably produce unintended changes in the timing or phasing.

Secondly, undesirable consequences can result from the use of pressurized engine oil as the actuating force for operating the prior variable valve timing systems described above. The rotation of the two shaft, including the camshaft and the piston actuator, tends to act as a centrifuge with respect to the oil and resultantly separate solids in the oil

from the remaining liquid portion. These solids can be deposited adjacent the periphery of the actuator piston and accumulate sufficiently to eventually interfere with the smooth reciprocal operation of the actuator piston. Furthermore, seals for containing the oil will wear and then the mechanism likely will develops either internal or external oil leaks. In addition, operation of this type of oil pressure actuated mechanism under cold conditions can be very sluggish due to the high viscosity of the oil.

Ideally, a compact variable timing device or mechanism that selectively provides infinite timing or phasing changes is sought. Such a mechanism would be desirable for timing an engine camshaft with respect to the engine's crankshaft for achieving a true variable valve timing system. The ideal mechanism would also be desirable for timing or phasing an input shaft of an engine distributing type fuel injection pump as is commonly used for diesel or other direct injection type engines, thus providing selectively timed fuel injection. In either application, what is needed is a shaft timing mechanism that can be either retarded or advanced relative to the crankshaft in a precise fashion in response to operating conditions of the engine.

SUMMARY OF THE DISCLOSURE

In accordance with one aspect of the invention, a selective timing or phase adjusting mechanism between one rotatable driving shaft and a driven output shaft, such as a camshaft, includes a drive member which is coaxially mounted and axially affixed with respect to the driving shaft for rotation together. An intermediate connecting member is coaxially mounted with respect to the rotatable driving shaft and the drive member and is capable of axial movement relative to both and angular motion with respect to either the driving shaft or drive member when conducting its relative axial movement. The intermediate connection and coupling member is connected to a geared device that is selectively activated by an electric motor which produces axially movement of the intermediate connection and coupling member with respect to the rotatable drive shaft and driving member to any desired axial position between predetermined first and second position. The gearing device provides a unidirectional drive system which allows the motor to drive the mechanism, providing the optimum shaft phasing, but protects against torque forces self exerted by the shaft from changing the desired shaft phasing.

Preferably, the gearing device is operably connected to a sleeve rotatably free with respect to said intermediate connection member and axially affixed relative thereto. The gearing device when in operation axially moves the sleeve which in turn axially moves the intermediate connection member with respect to both the driving member and the shaft.

The intermediate connection member is a axially shifting bar or pole that has helical splines that rotationally affix the bar to either the driving member or the shaft and allow relative rotation of the bar with respect to one of the driving member and shaft upon relative axial motion.

In one embodiment, the gearing device is a worm gear that axially drives the sleeve. In another embodiment, the gearing device is a threaded lead screw engaging complementary threads on the sleeve. In another embodiment, the gearing device is in part a gear sprocket that has an internally threaded hub that engages complementary external threads on the sleeve. The gear sprocket may engage a pinion gear connected to the output shaft of the electric motor.

In one embodiment, the rotatable shaft is hollow and defines a hollow interior. The driving member is rotatably mounted proximate one end of said hollow rotatable shaft and the gearing device is mounted proximate a second end of the hollow rotatable shaft. The driving member is connected to the gearing device through the hollow interior of the rotatable shaft.

In one embodiment, the timing device is incorporated in a valve timing device for an internal combustion engine where the driving member is a cam gear or sprocket that is mounted on one end of the camshaft for angular rotation with respect thereto. In one embodiment, the intermediate connection member is a shifting bar that is at least partially mounted for axial sliding motion within the camshaft.

In one embodiment, the mechanism is disposed within a dedicated housing mounted between the timing drive train of a diesel engine and its fuel injection pump, thus providing optimized injection timing for correct operation of the diesel engine under all conditions of speed, load, temperature, etc.

It is desirable that the electric motor is operably connected to an electronic control unit that reads input parameters of the internal combustion engine and produces a motor controlling output signal to the electric motor in response to the input parameters to provide the optimum valve timing in accordance with the input parameters.

In this fashion, variable valve timing is achieved for any and all desirable parameters to achieve optimal valve timing. The variable timing is achieved in a variety of packages contours depending on the space availability about the camshaft and engine. The electric motor provides for precise and stable intermediate positions. The gearing between the electric motor and the cam or fuel pump locks the position against any torque forces that may be exerted by the input driving member or reverse torques exerted onto the output shaft i.e. camshaft.

In addition to the variable valve timing achieved by the mechanism as described above, the same mechanism is available to drive a fuel injection pump. This application would allow the fuel injection timing to be varied corresponding to similar engine parameters and characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference now is made to the accompanying drawings in which:

FIG. 1 is a schematic representation of the subject mechanism as applied to variable valve timing for an engine camshaft driven by the engine crankshaft; and

FIG. 2 is a schematic representation of the subject mechanism as applied to variable fuel injection timing for a fuel pump driven by the engine crankshaft for directing fuel to specific combustion chambers in timed sequence; and

FIG. 3 is a perspective and partially broken away and sectioned view of one embodiment of a selective variable timing or phasing mechanism for engine valving; and

FIG. 4 is fragmentary and top plan, partially sectioned view of the one embodiment and illustrating an electric motor and gear mechanism for producing timing changes between the engine crankshaft and camshaft and illustrating a shifting sleeve member in alternate extreme positions;

FIG. 5 is a graphical representation of an electronic control system for the camshaft variable timing system shown in FIGS. 3 and 4;

FIG. 6 is an elevational and partially sectioned side view of a second embodiment of the subject invention; and

FIG. 7 is a plan and partially sectioned side view of a third embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGS. 1 and 2, an internal combustion engine 1 is schematically illustrated in block form. Engine 1 has an engine block portion 2 and a cylinder head 3. Block 2 and cylinder head 3 are attached together in a manner well known in the engine art. A projecting end portion 4 of a crankshaft is shown in FIGS. 1 and 2.

In FIG. 1, the selective rotary adjusting mechanism is shown being used for providing selective variable camshaft 4 timing or phasing of the engine camshaft relative to the engine crankshaft. Mechanism 5 basically transfers rotary motion of the crankshaft to the camshaft which is mounted for rotation on the cylinder head and covered by a valve cover attached to the cylinder head (not shown in FIGS. 1 and 2). Specifically, rotary motion from the end 4 of the crankshaft is transmitted to the mechanism 5 by gearing, a belt drive, or by a chain drive (no specific means is shown except schematically). All of these transmittal devices are well known in the engine art. The exact operation working of the mechanism 5 will be detailed hereinafter.

In FIG. 2, the rotary adjusting mechanism 5 is shown being used for providing selective variable fuel injection timing for a rotary fuel pump 6. This particular type of fuel pump is commonly used for a diesel engine and in addition to pressurizing and pumping fuel it also distributes a quantity of fuel to each combustion chamber in a sequence controlled by rotation of the crankshaft. As is shown in FIG. 1 and explained previously, the engine crankshaft 4 and the mechanism 5 are operably connected for rotation together. Also, the fuel pump 6 is connected by a shaft 7 to the mechanism 5 for rotation together. Fuel inlet or outlet conduits are not shown in FIGS. 1 and 2 but would be used and would extend from a vehicle fuel tank to the pump and from the pump to the various combustion chambers of the engine.

It could be expected and understood that either of the two applications of mechanism 5 or both applications might be used as suggested in FIGS. 1 and 2.

First Embodiment

Referring now to FIGS. 3 and 4, a first embodiment of the invention is shown as it is applied to an application for a selective variable valve timing. The application utilizes a chain or a gear-driven transmission between the crankshaft and the camshaft of an associated internal combustion engine as will be apparent from the following description. It should be understood that the invention is also useful for many other similar selective timing and phasing application such as a diesel fuel injection pump in which it is desired to change the phase relation between the output of a rotary driving shaft and a rotary driven shaft, either advancing or retarding the driven shaft with respect to the driving shaft.

FIG. 3 illustrates the forward end portion 10 of the driven camshaft of an associated engine which is supported for rotation on a front bearing assembly of the saddle type including a semi-cylindrical bearing surface 11' formed in an upstanding portion 11 of the engine's cylinder head 3. The end 10 of the camshaft is retained against bearing surface 11' by a bearing cap member 12 defining a semi-cylindrical bearing surface 12'. Cap member 12 is secured to the upstanding cylinder head portion 11 by fasteners 14 (Only one of two shown).

The camshaft is driven by rotation of a camshaft input gear 16 having a plurality of teeth 16'. Gear 16 itself is adapted to be engaged by another gear (not shown) which would be operationally engaged or caused to rotate along with the engine crankshaft. Alternately, it should be realized that the member 16 could be configured to be engaged by a chain which would partially encircle it as well as also engaging a sprocket preferably on the engine crankshaft.

In the preferred embodiment shown in FIG. 3, the gear **16** encircles a cylindrical bearing sleeve **17** located about an outer cylindrical surface of the camshaft end **10**. The gear **16** and bearing sleeve **17** are secured from movement axially by a thrust shoulder **18** which is integrally formed on the end portion **10** of the camshaft and by a washer **19** retained on camshaft end **10** by a snap ring **20** within a groove **22**. Located radially inward from gear **16** and sleeve **17** is an end bore forming a cavity **24** in the end portion of the camshaft. A portion of the internal, cylindrical wall surface of the cavity **24** is configured with a series or set of straight, internal splines **26**.

As seen in FIG. 3, the leftward or inboard end portion **27** of a shifting stub shaft **28** extends into an end cavity **24** formed within the end of the camshaft. This inboard end portion **27** carries a series or set of external, straight splines **30** thereon which are complementary to the internal, straight splines **26** presented by a portion of the internal wall of the camshaft end **10**. The series of splines **26** and splines **30** are adapted to mesh together causing both shafts to rotate with one another. The engaged series of splines **26** and **30** also allow the stub shaft **28** to move in an axial direction relative to the camshaft end **10** without changing the relative angular relationship between camshaft and stub shaft. Concerning axial movements of the stub shaft, it has a radially outwardly projecting collar stop **32** which engages the end surface of the camshaft end portion **10** when the stub shaft **28** is in its extreme leftward axial position which is shown in FIG. 3. This establishes the furthest axial leftward movement of stub shaft **28**. The collar stop **32** may be integrally formed of shaft **28** or be separately formed and welded thereon. The rightward or outboard end portion **34** of stub shaft **30** has a series of external, helical splines **36** formed thereon.

A hub member **38** having a generally tubular rightward or outboard end portion **39** defining an internal cylindrical aperture **40** is mounted about the outboard end portion **34** of the stub shaft **28**. The configuration of the internal cylindrical aperture **40** is adapted to accommodate the sliding movement of the stop collar **32** axially therethrough. The outboard end portion **34** of member **38** forms a set or series of internal helical splines **41** formed therein which are complementary to the set or series of external splines **36** formed in outboard end portion **34** of the stub shaft **28**. The two series of splines **36**, **41** permit slidable axial movements of the stub shaft **28** relative to the hub member **38**. Because of the helical nature of the series of splines, the axial movement between members **28** and **38** results in a change in their angular timing or phase relationship.

An enlarged internal aperture part of the leftward or inboard end portion **43** of the hub member **38** concentrically encircles a shoulder portion **42** of the input or driving gear member **16** and further has a substantial radially outwardly extending flange portion **44**. The flange portion **44** overlies and engages a side surface of gear member **20** as shown and is secured thereto by a plurality of circumferentially spaced bolts **45** (only one of which is shown). Each of the bolts **45** extends through a circumferentially extending slot **45'**. Conventional lock washers inhibit loosening rotation of the bolts **45** as shown in FIG. 3. The circumferentially extending slots obviously permit a wide degree of angular adjustment between the members **16** and **38**.

A generally cup-shaped drive sleeve member **46** has a cylindrical configuration with a closed end portion **46'** and an interior defined by an interior wall or surface **46"** permitting it to be positioned about the outside surface **47** of the hub member's end portion **39**. The end portion **46'** is configured with a series of internal, helical splines **48** adapted to slidably engage the corresponding external, helical splines **36** on the outboard end portion **34** of the stub shaft **28**. The end portion **46'** of the drive sleeve **46** is axially connected to the end portion **34** of the stub shaft **28** by a pair of snap rings **49** seated in a respective grooves **50** formed in the outboard end **34** of the stub shaft **28**.

The axial fixation of the drive sleeve **46** to the shifting stub shaft by the snap rings **49** enables the drive sleeve **46** to cause movement of the shifting stub shaft **28** in an axial direction relative to the axially stationary camshaft **10** and hub member **38** as permitted by the limits applied by the accommodation of the stop collar **32** within aperture **40** of hub member **38**. The possible axial movement is better understood by reference to FIG. **4** which shows the two extreme positions of the drive sleeve **46** as well as stub shaft **28** (note the projecting rightward or outboard end). Again, at one extreme, the stop collar **32** abuts the end surface of the camshaft **10** and at the other extreme position the stop collar **32** engages an internal shoulder stop **50** machined within the hub member **38**. Obviously, the surfaces defined by the outside diameter **47** of the flanged hub member **38** and the inside diameter **46"** of the drive sleeve **46** must be accurately formed and sufficiently finished to allow both sliding movement between members and the desired small degree of relative angular rotation resulting from the helical nature of spline series **36** and **41**. It is also important to maintain a sufficient degree of concentricity to provide smooth operation.

As best shown in FIGS. **3** and **4**, a series of circumferentially continuous and axially spaced tooth formations **51** formed are formed on the external cylindrical surface **52** of the drive sleeve **46**. This provides the rack-like formation in a known rack and pinion type gear arrangement. Each of the tooth configurations has a gear-shaped profile. The teeth **51** extend parallel to one another axially along the drive sleeve member **46** and are engaged by similarly profiled teeth of a pinion gear **54** on a shaft **56** with an axis "B" extending transversely to the axis "A" of the mechanism discussed above.

The mechanism as illustrated in FIG. **4** shows a top planar view of the mechanism as compared to the side view shown in FIG. **3**. In addition, housing structure is added to show how shaft **56** with its pinion gear **54** is mounted at opposite ends by a pair of ball bearing assemblies **58** and **60**. The bearing assemblies **58**, **60** are supported by a cover housing **61** within which the mechanism operates. A bull gear **62** of a worm-gear drive is attached to the upper end of the shaft **56** as shown in FIG. **4**. Bull gear **62** meshes with a lower worm pinion gear **63** which is mounted on a midportion of a shaft **64**. Shaft **64** is mounted for rotation by two ball bearing assemblies **65**, **66** which are supported by housing **61**. The axis "C" of the shaft **64** driving the worm gear pinion **63** lies in a plane parallel to axis "A" of the mechanism best detailed in FIG. **3**.

Shaft **64** is operably attached to a variable phased drive motor (reversible D.C. stepper motor) **67** which is suitably attached to the cover housing **61** by screws **68**. The output shaft **64** is either directly connected to the worm pinion gear **63**, as shown, or operably connected indirectly through an integral reduction gear (not shown).

The selective phase adjusting mechanism illustrated and described above can be advantageously utilized to control timing or phasing of the camshaft of an internal combustion engine relative to rotation of the crankshaft. In most engines, the timing or phase relationship between camshaft and crankshaft is set and is not adjustable. However, various engine related operational conditions or parameters, such as speed, load, temperature or other operative factors, are functional factors that together relate to an ideal timing or phasing of the camshaft relative to the crankshaft. Many of the same factors are already included as control parameters for ignition timing or for fuel injector operation on modern electronically-controlled engines. The parameters or factors, labeled **68** in FIG. **5** are sensed by various devices (not shown) and inputted as signals **70** to an electronic control unit **72** (ECU). The ECU is preferably the same unit controlling the other engine functions (injector operation, spark or injection timing, E.G.R. rate, etc.). The ECU **72** produces an appropriate desirable output control signal **74** in the form of an appropriate number of control pulses, which are fed to the stepper motor **67**. The motor **67** responds by producing a discrete planned rotation of its shaft **64** resultantly operating its mechanical gearing, including worm pinion gear **63**, worm gear **62**, pinion gear **54**, and rotary rack teeth **51**. This changes the axial positioning of the drive sleeve **46** and attached shifting stub shaft **28**. Thus, the shifting stub shaft is axially moved in proportion to the number of pulse signals from the ECU **72** for achieving the desired angular phasing of the camshaft **10** relative to the drive input (gear **16**). The computer or ECU **72** keeps track of the number of pulses fed to the stepper motor **67** and retains in its memory the exact angular rotation of its output shaft. Thus, the total relative phasing of the camshaft **10** with respect to the input gear **20** is known to the ECU such that no position feed-back device or data is needed by the ECU.

An alternative drive for stepper motor **67** would be a regular reversing D.C. motor. However, in this case, a position feedback signal would be required for the ECU to properly locate the sleeve **50** following a pre-programmed computer algorithm. A feedback signal can be generated by a multitude of easily available sensors (not shown), including for example a linear variable differential transformer (LVDT) attached to drive sleeve **50** to monitor its axial position. Other examples might include a linear potentiometer to perform the same function, or a rotary potentiometer to monitor the number of turns of the pinion shaft **56** or worm pinion shaft **64**.

The rotary teeth **51** formed on drive sleeve **46** could be replaced by a non-rotating linear rack attached to the exterior surface **52** if the connection of the drive sleeve **50** to the shifting stub shaft **28** is through a bushing member or a ball bearing coupling (not shown). Furthermore, the spline sets on the camshaft **10**, the shifting stub shaft **28**, the hub member **38**, and the drive sleeve **46** could be replaced by appropriate spherical or cylindrical rollers fitted within appropriately shaped grooves in the respective members.

In FIG. **6**, a second embodiment of the selective adjustable timing or phasing mechanism is illustrated as applied to controlling camshaft timing or phasing. This particular timing mechanism **200** is designed for mounted inside a typical 40 mm diameter of an intake camshaft **202**. Such a camshaft would be appropriate for use with a four-valve, double overhead camshaft diesel engine such as used in trucks, for example. The adjustable phasing mechanism **200** is driven directly by an external reversible stepper motor **204** which is mounted forward of the front end of camshaft **202**, and exteriorly to a cover plate **205**. The camshaft **202** includes a front or outboard end portion **206** with a camshaft journal **207** which is supported for rotation by a semicylindrical journal portion **208** formed in the cylinder head and a bearing cap **209**. Axial movement of the camshaft **202** is prevented by including a thrust shoulder **210** disposed in the center of the journal **207**. Shoulder **210** extends into a grooves **211**, **212** formed respectively in the cylinder head and bearing cap **209**.

One or more notches or teeth **213** may be machined on the peripheral edge of the thrust shoulder **208**. A magnetic sensor pick-up **214** may be mounted on the bearing cap **209** radially outwardly from sensor **214**. The sensor **214** is connected to an ECU through proper electrical connections (not shown).

A driving gear **215** is rotated by the rotative operation of the engine's crankshaft which has a driven gear (not shown) attached thereto which is operatively connected to the driving gear **215** in a conventional manner known in the engine art. The driving gear **215** is positioned adjacent a front or outboard face **216** of the engine cylinder head. At either side of the gear **215** are portions of the cover plate **205** and a timing gear housing or case **217**. Members **205** and **217** are attached to the wall portion **216** of the cylinder head by conventional fasteners (not shown). The driving gear **215** is mounted concentrically about the end portion **206** of the camshaft **202**. A flange portion **218** of a bushing extends adjacent the side surface of the gear **215** and a pilot shoulder portion **219** of the bushing is positioned within an interior bore **220** formed in the end of the camshaft. The flange **218** is attached to the driving gear **215** by a plurality of cap screws **221** which are inserted through circumferential slots **222** in the flange **218**. The cap screws **220** are inhibited from loosening rotation by conventional lock washers.

The driving gear **215** is prevented from leftward axial movement on the end **206** of the camshaft by a snap ring **223** which is disposed in a groove **224** formed in the camshaft's end portion **206**. The cap screws draw the flange **218** against the end surface of the camshaft end portion **206** to prevent rightward axial movement of the connected flanged bushing and driving gear **215**. In addition, a set or series of internal straight splines **225** is formed along the interior diameter surface of the pilot shoulder portion **219** of the flanged bushing.

In addition to the pilot shoulder **219** of the bushing located within the camshaft's interior bore **220**, another bushing member **226** is also mounted therein. Specifically, a bushing member **226** is mounted therein preferably by shrink fitting or press fitting it so that the bushing and the camshaft are substantially integral. The bushing **226** is formed with a set or series of internal helical splines **227** along its inside diameter. An axially shifting hollow sleeve member **228** is located within the interior bore **220** of the camshaft and between the one set of internal straight splines **225** and the other set of internal helical splines **227**. Shifting sleeve member **228** has a first set or series of external straight splines **229** and a second set or series of external helical splines **230** respectively engaging the series of internal straight splines **225** of member **219** and the series of internal helical splines **227** of member **226**. A radially outwardly extending stop shoulder or flange **231** is formed on the midposition of the shifting hollow sleeve member **228**. The shoulder **231** shifts axially with the sleeve member **228** and slides in an axial direction within an annular space **232** limited at its ends by the bushings **219** and **226**.

In FIG. **6**, the inboard or rightward end portion of the shifting sleeve member **228** is connected to a leftward end portion of a carrier sleeve member **233**. Specifically, a radially inwardly directed annulus or shoulder **234** of sleeve member **233** terminates at an inward edge **235** which encircles the rightward end portion of the sleeve member **228**. The shifting sleeve member **228** carries a snap ring **236** which is firmly mounted in a groove in the rightward end of member 228. Engagement of the shoulder 234 and its edge 235 with the snap ring 236 linkingly connects sleeve members 228 and 233 for mutual axial movements together while permitting relative rotational movement therebetween. Thus, the carrier sleeve 233 is free to rotate with respect to the shifting sleeve 228. Alternatively, the sleeve members could be secured together by matching internal splines (not shown).

The carrier sleeve 233 is mounted within the internal bore 220 of the camshaft. More specifically, an outside surface 237 of the sleeve 233 is slidable against the internal diameter surface of the camshaft's bore 220 which acts as a guide-bearing surface.

A nut member 238 with a cylindrical exterior configuration is disposed within a correspondingly configured interior formed in the carrier sleeve 233. The nut member 238 is free to rotate within the sleeve but is restrained axially by engagement at one end with the end 239 of the shifting sleeve 228 and by engagement at the opposite end with a snap ring 240 which seats in a groove 241 located at the rightward or inboard end portion of carrier sleeve 233. The nut member 238 has a threaded bore 242 formed through the leftward or outboard end portion. Preferably, the threaded bore has an acme type thread configuration. A jack shaft 243 extends through the nut member 238 and also carries acme screw threads 244 which are formed on the outer cylindrical surface at the rightward or inboard end of the jack shaft. The unthreaded leftward portion of the jack shaft 243 extends into the interior of the shifting sleeve member 228. Shaft 243 has an enlarged end portion 245 which engages the encircling wall of the sleeve member for providing an accurately guided but relatively frictionless movement between the members 228 and 243.

A quill-shaft 246 extends coaxially within the camshaft with an end portion which extends through an aperture 247 in the camshaft's rightward end. Oil leakage from the camshaft interior is blocked by a seal member 248 carried by the camshaft and encircling the quill-shaft 246. The quill-shaft 246 is retained by engagement of a threaded shank portion 249 of the 246 with corresponding threads formed in a rear wall portion 250 of the cylinder head. A headed portion 251 is engaged to rotate the quill-shaft 246 and consequently tighten the shaft relative to the cylinder head's rearwall 250. A soft copper washer, or other such similar function device, is inserted under the headed portion 251 to inhibit any oil leakage.

Accordingly, the quill-shaft 246 is secured in a stationary and non-rotating posture. A set or series of straight exterior splines 252 are formed on the leftward or outboard portion of the quill-shaft 246 and a corresponding set or series of internal straight splines 253 are formed in the rightward or inboard end of the nut member 238. The two series of splines 252, 253 prevent rotation of the nut member 238 but permits axial movement with the carrier sleeve 233 and linked shifting sleeve 228.

The previously identified reversible stepper motor 204 is mounted at the forward end of the engine to the cover plate member 205 by a plurality of cap screws 254 (only two are shown). The motor has a drive shaft 255 which engages the leftward or outboard end 256 of the jack shaft 243 through an Oldham coupling 257 or its functional equivalent. The rear or inboard half-portion 258 of the Oldham coupling is secured to the jack shaft 243 by set screws 259 (only one of which is shown). A collar or flange 260 on the inboard half-portion 258 of the Oldham coupling 257 establishes the axial positioning of the jack shaft 243. The Oldham coupling 257 also has a forward or outboard-half 261 which is securely attached to the motor shaft 255 by set screws 262 (only one of which is shown).

For some engine applications with particular packaging requirements, it may be undesirable to mount the stepper motor 204 on the forward portion of the engine, as shown. When there is room at the rear portion of the engine, it would be simple to reverse the aforedescribed mechanism and install the motor on the rear of the engine.

In operation, the reversible stepper motor 204 responds to output pulse signals from the ECU of FIG. 5 and rotate a desired selective amount in either direction. The degree of motor rotation in response to the ECU pulses are counted or remembered by the ECU. In other words, the ECU has a memory on how many degrees, either way, the motor has turned. Alternatively, a common reversible D.C. motor could be used, but in this case, it would be necessary for provision of supplying the ECU with data on the camshaft position (feed back). This could be accomplished by the reaction of the magnetic sensor 214 to one or more notches 213 on the periphery of the thrust flange 210. By comparing the angular position of the notch or notches 213 to the angular position of the engine crankshaft, sensed by a similar magnetic pick-up, the ECU can determine the angular position of the camshaft and make corrections. The rotation of the motor's shaft 255 turns the jack shaft 243. Since the nut member 238 cannot turn because of the action of the stationary quill-shaft 246, the nut member 238 is moved in an axial direction. Movement of the nut member 238 simultaneously moves the carrier sleeve 233 in the same axial direction. The movement of the carrier sleeve 233 causes the linked shifting sleeve 228 to be moved in the axial direction. Therefore, we see that for any rotation of shaft 255, a corresponding axial movement is produced for the members 238, 233, and 228. Because of the differential angular effect between the set of helical splines 227 and 230, the aforedescribed axial movement of the shifting sleeve 228 causes a change in phase relationship between the drive through gear 215 and the driven camshaft bushing 226 and camshaft 202. Accordingly, this causes the phasing or timing of the camshaft to be selectively changed with, respect to the rotation of the engine crankshaft. The elongated. slots 222 in the flanged bushing provide a means for adjusting the phase of the camshaft with respect to the crankshaft in the initial engine set-up.

In some instances, it may be desirable to install the entire variable timing mechanism at the rear of the engine opposite the driven end. Such a mechanism can either be driven directly by an electric motor as shown or through a gear-train. Since the first two embodiments involved a direct-drive mechanism and a worm-drive system, a third embodiment 300 is illustrated in FIG. 7. The mechanism 300 is located at the rear portion of the engine and the camshaft. In particular, the mechanism is designated for a camshaft with a 30 mm diameter useful in a four-valve double overhead camshaft (DOHC) engine of relatively small displacement, such as a 550 cc per cylinder engine (a four cylinder 2.2 L engine).

On the left in FIG. 7, a camshaft drive mechanism for an engine's valve train is illustrated including a forward portion 301 of an engine's cylinder head shown to the left. The rearward portion 302 of the cylinder head is illustrated to the right. The drive input of valve train mechanism from the crankshaft includes a drive sprocket assembly 303 such as could be rotated by a belt (not shown) which in turn is driven by a sprocket on the engine crankshaft (not shown). The sprocket assembly is attached to the forward end portion of an exhaust camshaft **304** by a bolt fastener **305**. Relative rotation between the sprocket and camshaft is prevented by a keyway connector **306** located therebetween. The forward or leftward end portion of the exhaust camshaft **304** is supported for rotation by a bearing assembly **307**. Likewise, the rearward or rightward end portion of the intake camshaft **304** is supported for rotation by another bearing assembly **308**.

The forward end portion of the exhaust camshaft **304** carries a driving gear **309** which is secured thereto for rotation with the camshaft **304** by a keyway connector **310**. The sprocket assembly **303** is located in a depressed space formed by the forward wall of the cylinder head and it is enclosed by a cover plate **311**.

The driving gear **309** carried by the exhaust camshaft **304** meshes with a second driven gear **312**. A forward end portion **313** of a intake camshaft **314** is supported for rotation by a bearing assembly **315**. Likewise, the Likewise, the rearward or rightward end portion of the intake camshaft **314** is supported for rotation by another bearing assembly **316**. Axial movement of **5** the camshaft **314** is prevented by formation of a thrust flange **317** on the camshaft's end portion **313**. The thrust flange **317** is captured in a annular groove formed in cylinder head and bearing.

The driven gear **312** is supported on the end portion **313** of the camshaft and is fixed in the axial direction on the right by a shoulder **318** formed on camshaft **314** and on the left by a snap ring **319** mounted in a groove formed in camshaft end portion **313**. Accordingly, this arrangement permits gear **312** to rotate about the end **313** of the camshaft **314** although as we will see, there is little relative rotation therebetween. What rotation that does occur takes place only during a period when the phasing or timing of the camshaft is being adjusted.

A flanged bushing member **320** is located to the left or forward of gear **312** and is centered by a slight shoulder **321** extending from the face side of the gear **312**. The bushing **320** is securely attached to the gear **312** by a plurality of cap, screws **322**. Each cap screw **322** is inserted through a circumferentially extending slot **323** in the flange member **320**. These slots permit a degree of relative angular adjustment between gear **312** and flange **321** during an initial engine set-up. The cap screws **322** are inhibited from any loosening rotation by lock washers or similar devices.

The intake camshaft **314** is tubular and has an inner bore **324** which extends axially therethrough. An elongated quill-shaft **325** extends through the inner bore **324** and past the rightward end portion of the camshaft. Quill-shaft **325** has a threaded aperture formed in its leftward end which is engaged by a bolt fastener **326**. A relatively large diameter washer **327** is secured to the end of the quill-shaft **325** with its outward peripheral edge pressed against the end of the flanged bushing **320**. A woodruff key connector **328** between the flanged bushing **320** and the quill-shaft **325** prevents rotation between members **320**, **325**. Accordingly, the gear **312**, flanged member **320**, and quill-shaft **325** are connected to rotate together as a unit in response to rotative input from the engine crankshaft.

The rightward end of the quill-shaft **325** has a set or series of external, axially straight splines **329** formed thereon. A second set or series of external, but helically extending splines **331** are formed on the rightward or rearward end portion **332** of the camshaft **314**. The rightward end portion of the camshaft **314** carries a stop washer **333** which has a set of internal splines formed thereon engaging the set of splines **331** of the camshaft. Stop washer **333** is axially fixed upon the camshaft **314**.

To the right of the end of the camshaft **314**, a shifting sleeve member **334** with an interior space is disposed about the rightward end portion **330** of the quill-shaft **225**. The shifting sleeve member **334** have a first set or series of internal, axially straight splines **335** and a second set or series of internal, helically directed splines **336** formed on its interior surfaces. The first series of internal, straight splines **335** correspond to and engage the series of external, straight splines **329** formed on the quill-shaft **325**. The series of internal, helical splines **336** on the shifting sleeve **334** correspond to and engage the series of external, helical splines **331** on the camshaft **314**.

It should be noted that the straight sets of splines **316**, **331** could be formed as helical splines and the helical sets of splines **333**, **341** could be formed as straight splines. Further, all the splines could be helical with a different angle formed between set **316**, **331** and set **333**, **341**.

A generally cup-shaped carrier sleeve **337** extends coaxially about the shifting sleeve member **334**. Bushings **338'** and **338"** are inserted therebetween. A thrust washer **339** is disposed about the shifting sleeve member **334** between a shouldered end **340** of the carrier sleeve **337** and a shoulder **341** of the shifting sleeve member **334**. The bushings **338'**, **338"**, and thrust washer **339** facilitates relative rotational movement between the shifting sleeve member **334** and the carrier sleeve member **337** with relatively little friction and wear. A snap ring **342** fitted into a groove formed in the rightward end of the shifting sleeve member **334** secures together both the shifting sleeve member **334** and the carrier sleeve member **337** for axial movement as a unit while permitting relative rotation therebetween. In the preferred embodiment, a thrust washer **343** is positioned between the snap ring **342** and the shouldered end **340** of the carrier sleeve member **337**.

In FIG. 7, numeral **344** identifies a threaded exterior surface formed on the end of carrier sleeve **337**. The threaded portion **344** is engaged by a similarly threaded interior bore **345** of a hub **346** encircling carrier member **337**. The hub **346** is central to a spur gear **347** having gear teeth **347'** formed along its circumference. The threaded engagement between portions **344**, **345** causes the carrier sleeve **337**, and shifting sleeve **334** to move in an axial direction as the spur gear **347** is rotated but restrained axially. The axial extent of the threaded portion **344** on member **337** must be sufficient to permit the desired degree of axial movement for members **334** and **337**.

The members **334**, **337**, and **347** are housed within an enclosure formed by a housing member **348** and a base member **349**. Members **348**, **349** are positioned adjacent the leftward end **302** of the cylinder head. Both housing **348** and base member **349** are attached to the rear end of the cylinder head portion **302** by cap screws **350** (two of which are shown). Portions of housing **348** and base **349** engage opposite side surfaces of gear **347** to sandwich it for the purpose of retaining it in axial directions while permitting the gear to rotate.

An electrical stepper type motor **351** is attached to the housing **349** by cap screws **352** (two of which are shown). The motor **351** is activated under the control of the ECU **72** which is shown in FIG. **5**. The ECU **72** activates motor **351** whenever a change in the camshaft timing or phasing relative to the crankshaft rotation is desired. A rotatable shaft **353** of the stepper motor **351** carries a pinion gear **354** which engages the teeth **347'** of the spur gear **347**. Activation of the motor **351** causes a rotation of shaft **353** and pinion gear **354**. This in turn rotates spur gear **347**. Since the spur gear **347** is fixed in the axial direction between housing **348** and base **349**, its rotation produces axial movement of the carrier sleeve member **337** through the threaded portions **344** and **345**.

An axially extending groove **356** is formed in the exterior surface **355** of the carrier sleeve **337**. An appropriately shaped and sized stator pin **357** is carried by a set screw **358** and extends into groove **356**. This prevents rotation of the carrier sleeve member **337** but permits it to move in an axial direction. Also, due to snap ring **342**, any axial movement of the carrier sleeve member **337** produces the same axial movement of the shifting sleeve member **334**.

Lubrication of the selective adjusting spline mechanisms is provided through drilled passages **359** extending from an oil feed **360** from the front cam bearing **315**. An end cap **361** plugs the through bore which forms the passage **359**. A small feed bore **362**, one of several, feeds oil to the splines **329**. The oil is allowed to drains back into interior of housing **348** and back to the cylinder head through appropriate passages (not shown).

The mechanism is operated to change or adjust the timing of camshaft **314** relative to the rotation of the crankshaft in response to an output signal generated by the ECU **72** (see FIG. **5**). First, stepper motor **351** is activated to rotate shaft **353** a desired angular amount appropriate for the phasing change desired. Accordingly, the pinion gear **354** and spur gear **347** are rotated desired amounts. The engagement between interior threads **345** in hub **346** and external threads **344** on the exterior surface **355** of carrier sleeve **337** causes a desired axial movement of the carrier sleeve **337** since rotation of the carrier sleeve is prevented by the stator pin **357** within groove **356**. Since the shifting sleeve **334** is axially blocked by shoulder **341** and snap ring **342** within the carrier sleeve, axial movements of the carrier sleeve **337** carry the shifting sleeve **334** along with it.

As previously discussed, the shifting sleeve **334** is connected to quill-shaft **325** through a pair of meshing sets of straight splines **335** and **329**, respectively. In addition, another portion of the shifting sleeve **334** is connected to the camshaft **314** through a pair of meshing sets of helical splines **336** and **331**. These splines normally cause the camshaft **314** and quill-shaft **325** to rotate together as a unit. However, during a change in camshaft timing or phasing, the axial movement of the shifting sleeve **334** causes the camshaft to rotate slightly relative to the quill-shaft **325** due to the engagement between set of helical splines. Accordingly, the phase change of camshaft **314** with respect to the quill-shaft **325** results in an angular change between the gear **312** (and sprocket on the crankshaft) This effectively changes the camshaft timing relative to the crankshaft while the engine is running and the mechanism and camshaft is rotation. In this manner, the camshaft can be advanced or retarded as the operational parameters of the engine dictate.

In this fashion, a relatively compact and therefore easily utilized variable valve timing mechanism is available with a substantial portion of the mechanism located within the camshaft itself. Also, the gear arrangement between the stepper motor and rest of the mechanism locks the resultant phase relationship securely in a desired condition to oppose any undesirable transient timing changes caused by reactive torque pulses related to the actions of the cam lobes and valve followers. Thus, a precise and reliable timing mechanism is achieved using mechanical shifters without any hydraulic fluid and attendant pressure concerns and seal problems.

It should be clear that variations and modifications of the inventive device and system are possible without departing from the scope and spirit of the present invention as defined by the appended claims.

The embodiments in which an exclusive property or privilege is claimed are defined as follows:

1. A phase controlling system between a rotatable driving member (**215**) and a rotatable shaft (**202**), said system characterized by:

said driving member (**215**) being coaxially mounted to and axially affixed with respect to said shaft (**202**) and angularly rotatable therewith;

an intermediate assembly including an axially shiftable member (**228**) coaxially mounted with respect to said rotatable shaft and said driving member capable of axial movement relative thereto and for angular motion with respect to one of said shaft and said driving member as it moves axially;

said intermediate assembly further including a carrier drive nut member (**238**) having an interior threaded portion (**242**) and being restrained from rotable movement but capable of axial movements relative to said shaft and said driving member;

means attaching said shiftable member (**228**) and said carrier drive nut member (**238**) for axial movement together;

a rotable jack shaft (**243**) coaxial with said rotatable shaft having an exterior threaded end portion (**244**) adapted to engage said interior threaded portion (**242**) of said carrier drive nut member (**238**);

said rotable jack shaft (**243**) being operatively connected to an electric motor (**204**) for selected rotation whereby subsequent relative rotation between said threaded portions produces selective axial movement of said carrier drive nut member (**238**) and shiftable member (**228**) with respect to said rotatable shaft and driving member between predetermined first and second positions;

said intermediate assembly (**228**, **238**, and **243**) providing a unidirectional drive, such as to allow the drive motor (**204**) to change the angular position of said shaft (**202**) with respect to said driving member (**215**) as set by said electric motor but to prevent torque forces exerted by said shaft to self-induce timing changes.

2. The shaft timing device as defined in claim **1** in which said rotable shaft is a fuel injection pump (**6**) with a rotatable input shaft (**7**) whereby the device is used to drive and time the operation of the pump.

3. The phase controlling system as defined in claim **1** in which said rotable shaft is a camshaft of an internal combustion engine.

4. The phase controlling system as defined in claim **1** in which said rotable shaft is a fuel injection pump (**6**) with a rotatable input shaft (**7**) whereby the device is used to drive and time the operation of the pump.

5. The shaft timing device as defined in claim **3** further characterized by:

said electric motor (**204**) having an output shaft (**255**) coaxial with respect to said camshaft and being operably connected to said jack shaft.

6. A shaft timing device as defined in claim **1** further characterized by:

said electric motor (**204**) being operably connected to an electronic control unit (**72**) that reads input parameters (**70**) of the internal combustion engine and produces a motor controlling output signal (**74**) to the electric motor in response to said input parameters to provide the optimum valve timing in accordance with said input parameters.

7. A shaft timing device as defined in claim **6** in which the electrical motor (**204**) is a stepper motor.

8. A shaft timing device as defined in claim **6** in which said electric motor (**204**) is a reversible direct current motor.

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